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(54) **ANGULAR VELOCITY SENSOR**

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G01C 19/5642 (2012.01)
G01C 19/574 (2012.01)

(52) **U.S. Cl.**

CPC ***G01C 19/5642*** (2013.01); ***G01C 19/574*** (2013.01)

(58) **Field of Classification Search**

CPC .. G01C 19/56; G01C 19/5642; G01C 19/574; G01P 3/44

See application file for complete search history.

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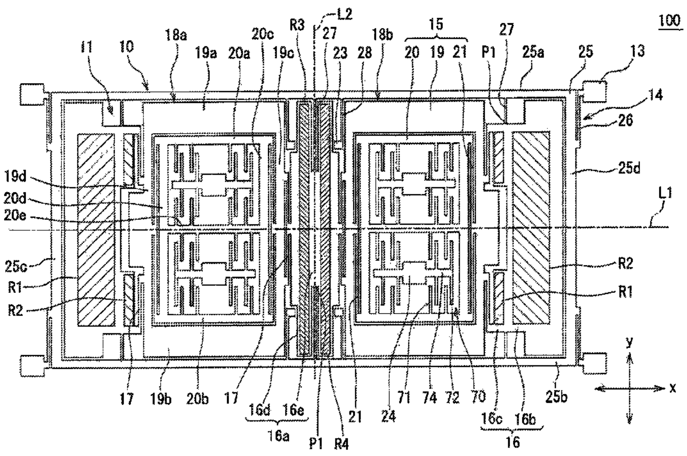
(57) **ABSTRACT**

An angular velocity sensor includes a vibrator located along x-y plane specified by x direction and y direction that are orthogonal to each other; a substrate that is separated away from the vibrator along z direction perpendicular to the x-y plane; an anchor device extended from the substrate to the x-y plane in which the vibrator is located; a linkage beam device that links the anchor device to the vibrator, the linkage beam being able to twist about the y direction; an excitation portion that vibrates the vibrator along the z direction; and a detection portion that detects an angular velocity based on a displacement along the x direction of the vibrator. The vibrator includes a linkage region to link with the linkage beam device, and the linkage region becomes a wave node when the vibrator vibrates along the z direction.

31 Claims, 11 Drawing Sheets



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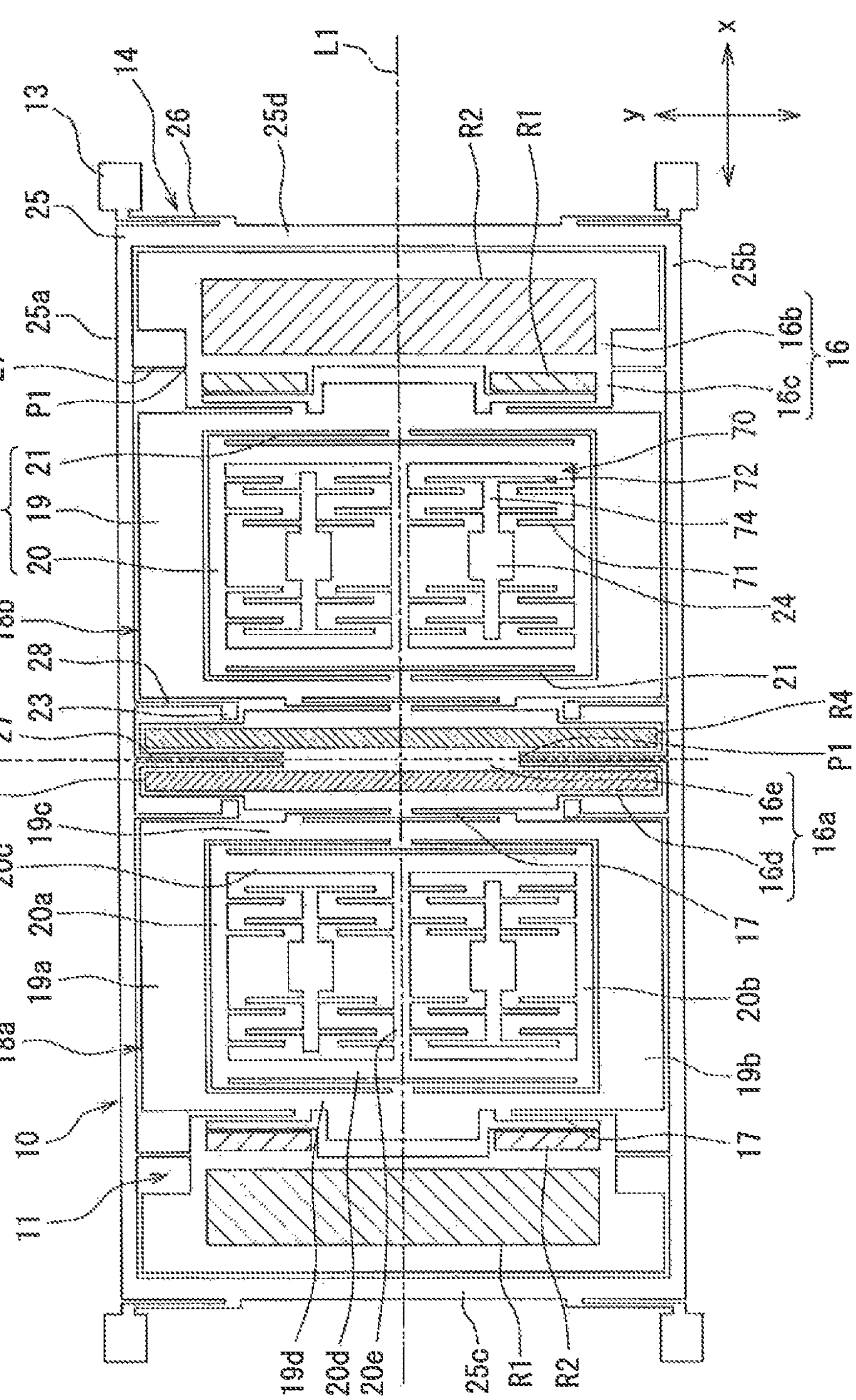
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FIG. 1

FIG. 2

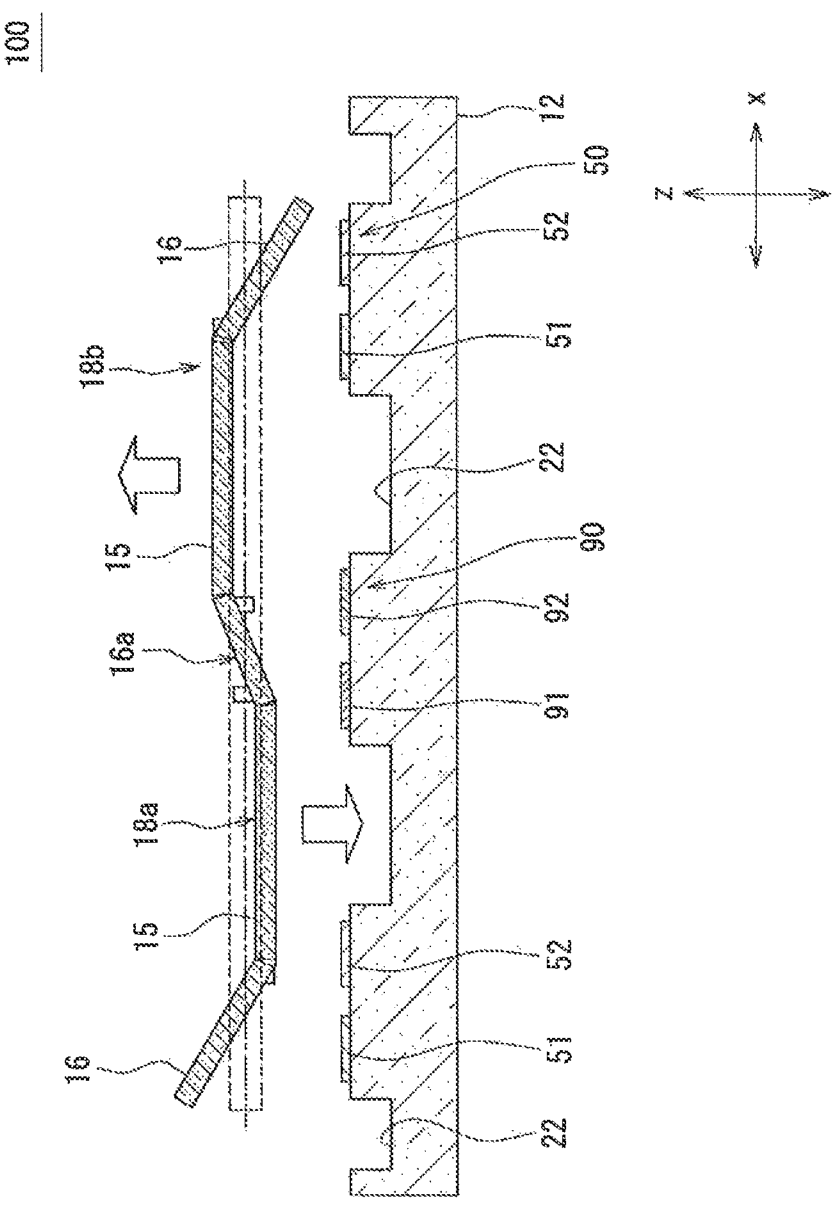
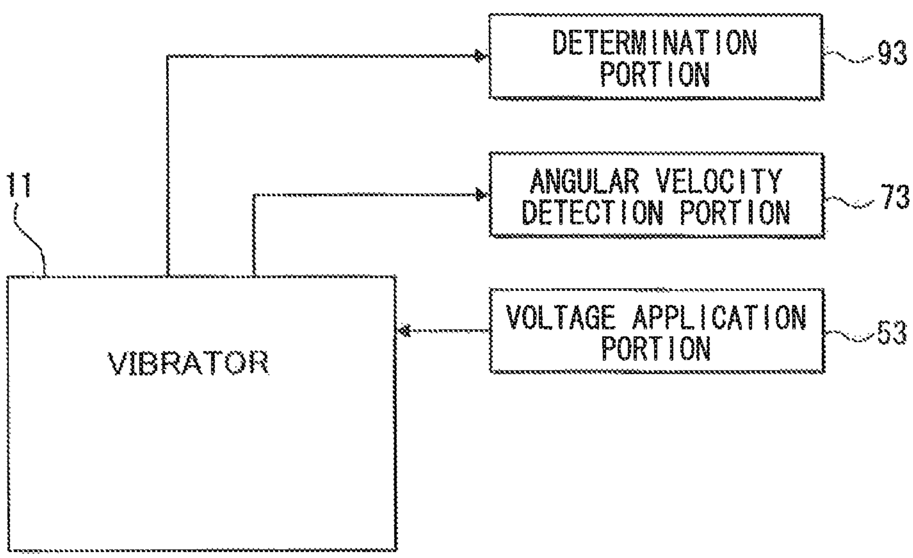


FIG. 3


DETERMINATION PORTION
93
ANGULAR VELOCITY DETECTION PORTION
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11
VOLTAGE APPLICATION PORTION
53
VIBRATOR

FIG. 4

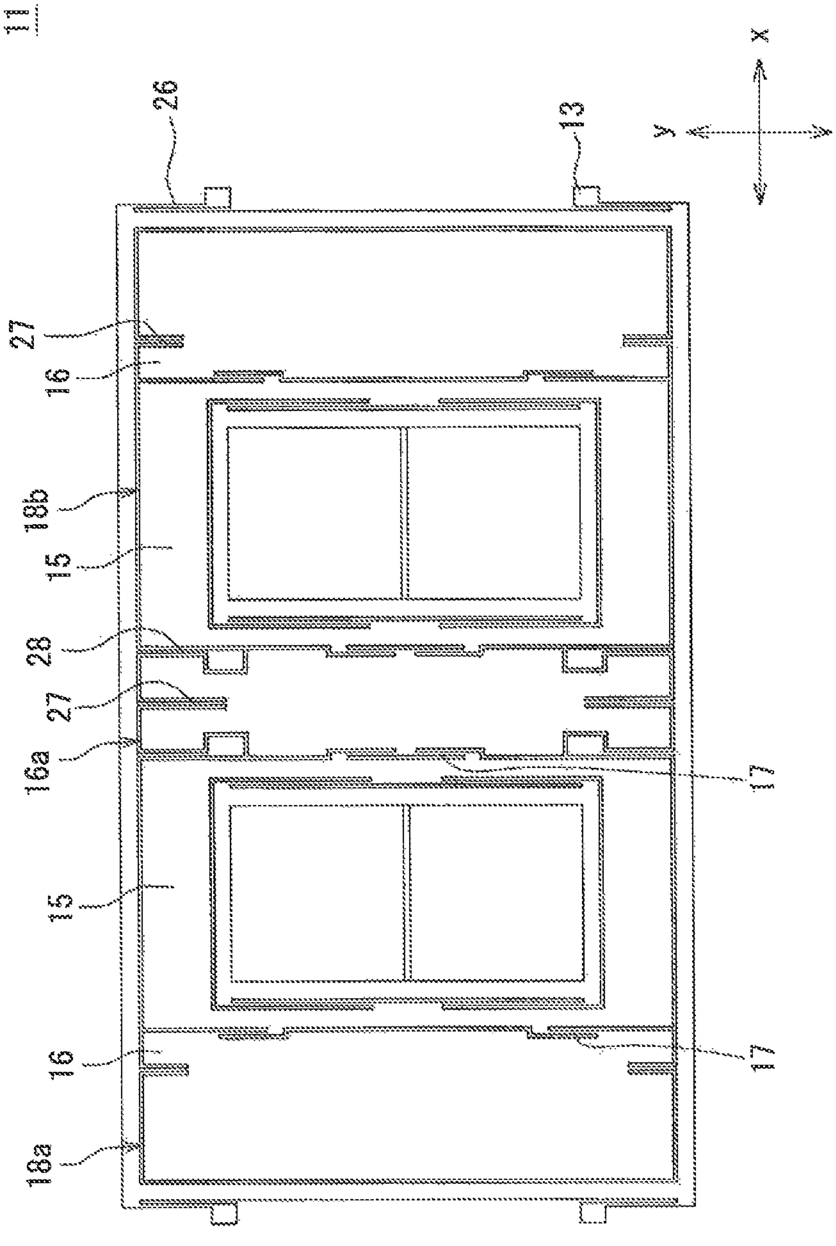
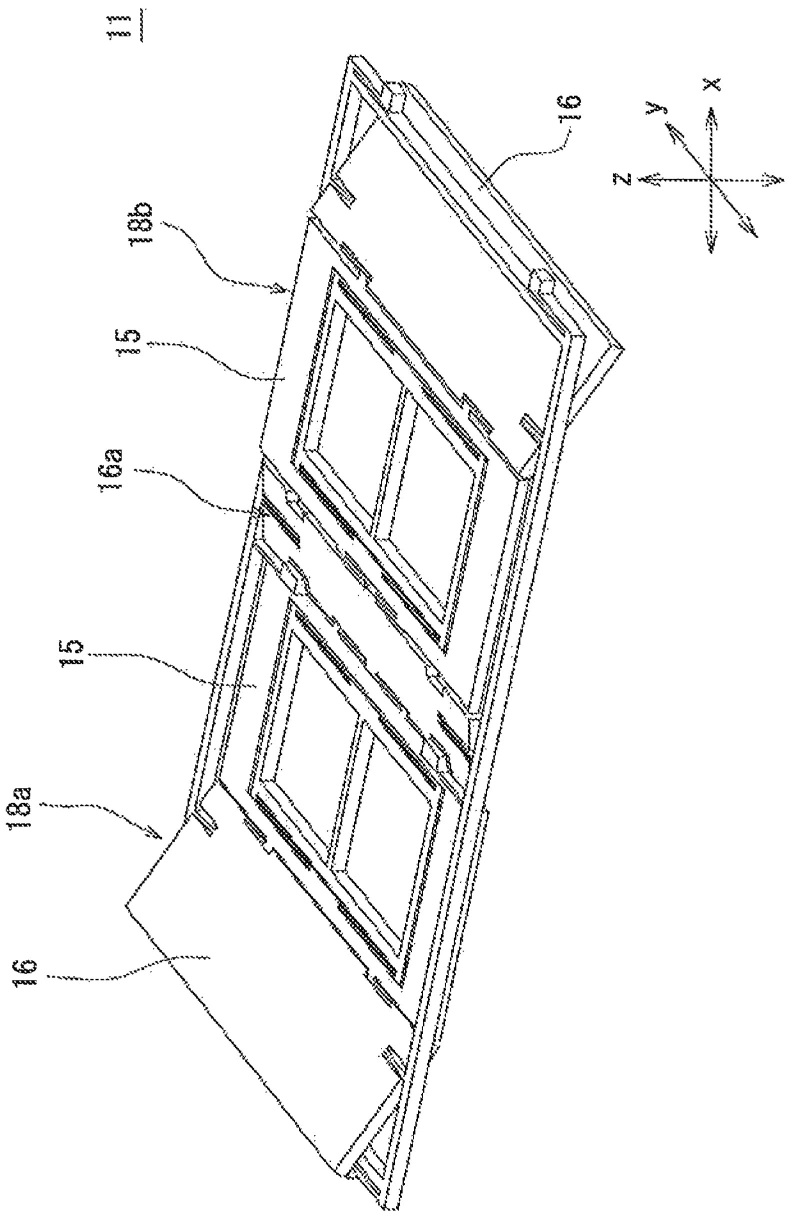


FIG. 5



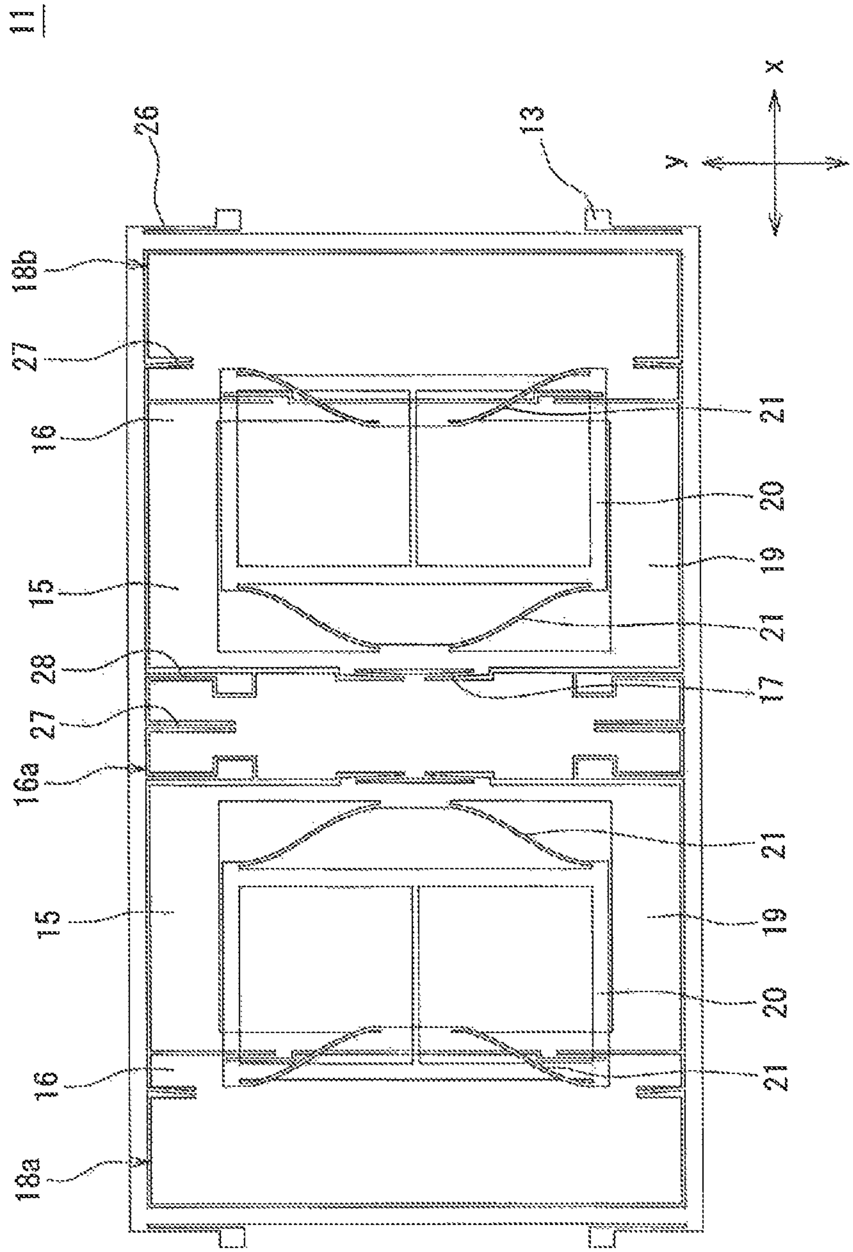
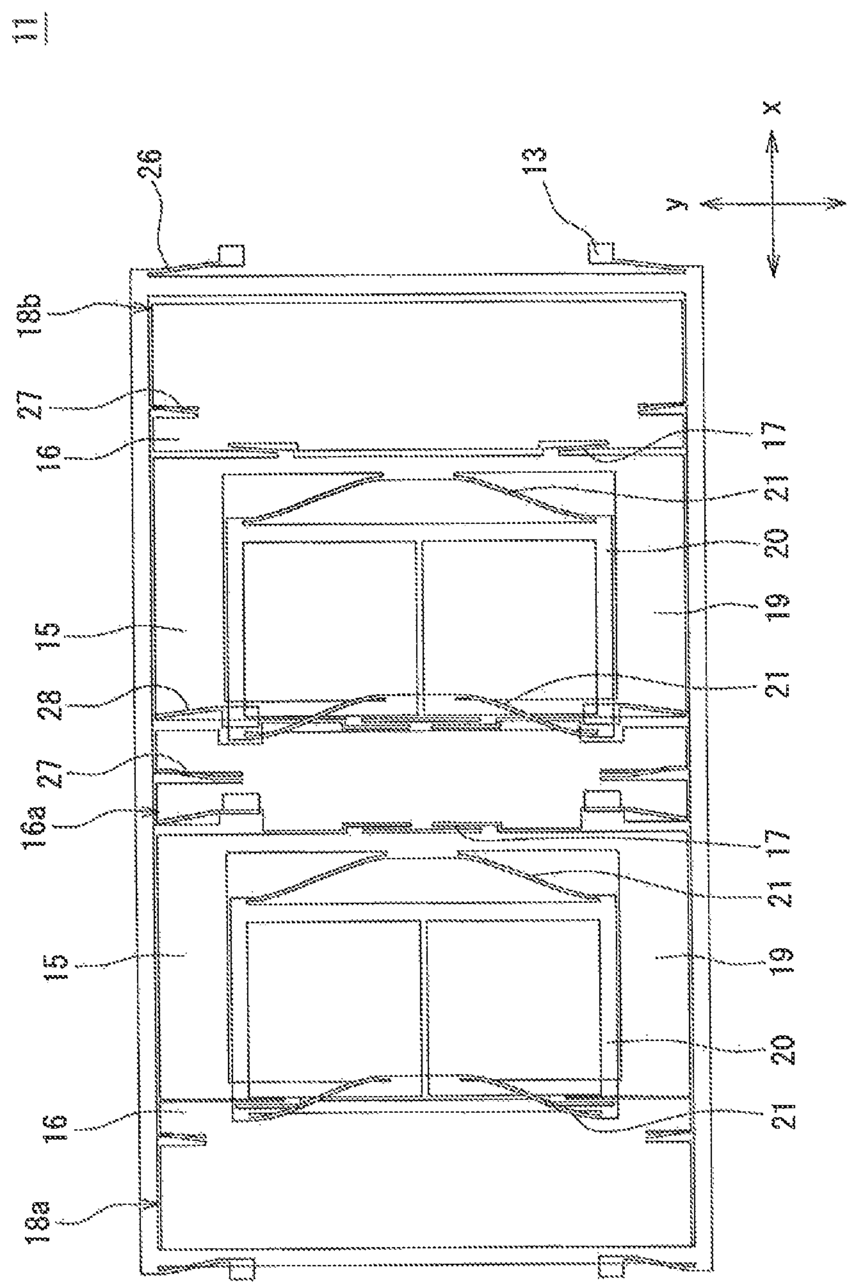


FIG. 6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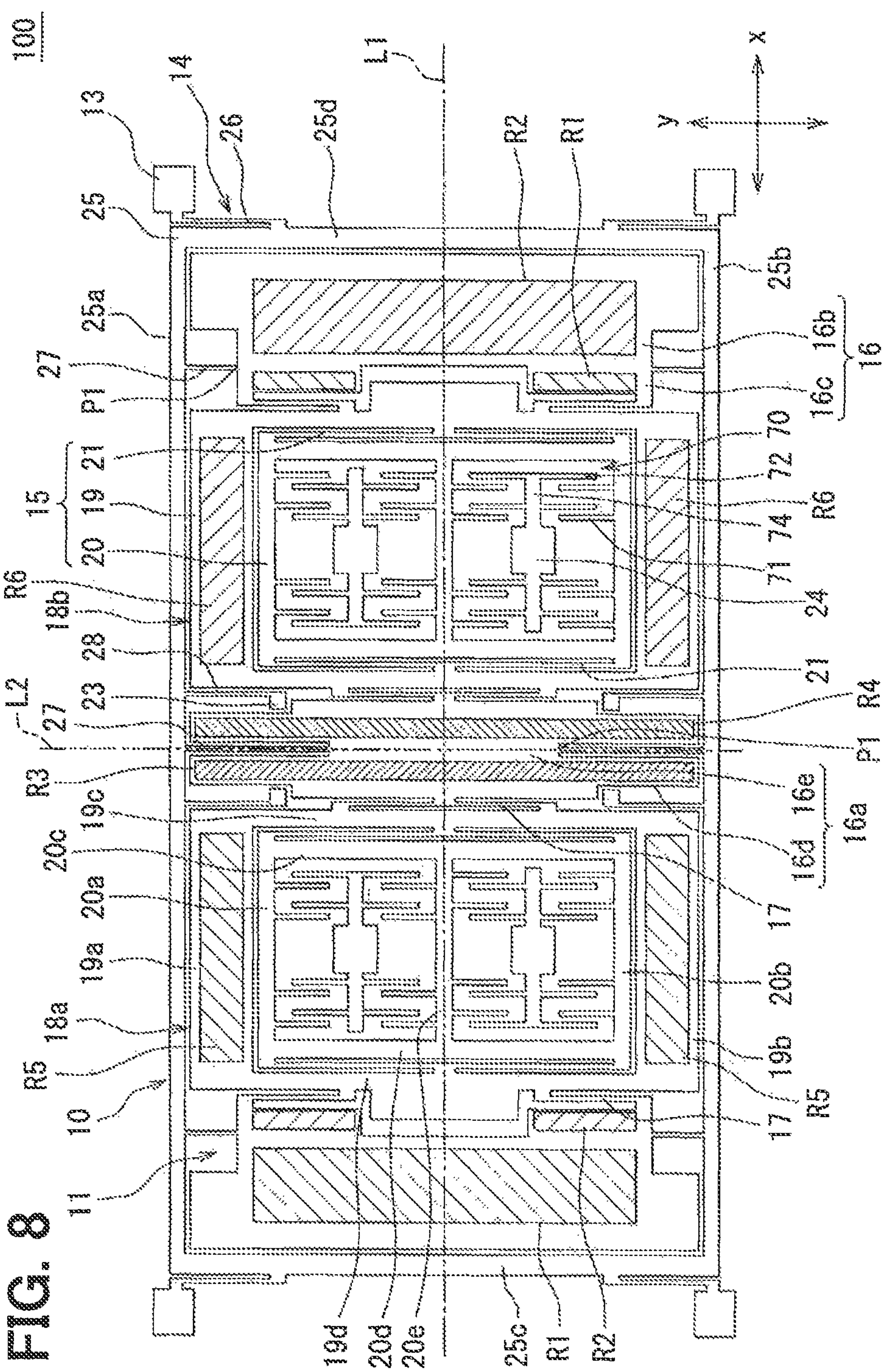
18a

FIG. 7

FIG. 8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71
24
R6
18b
28
23
L2
27
21
R4
P1
R3
19c
16e
16a
16d
20c
20a
17
19a
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20d
20e
25c
R1
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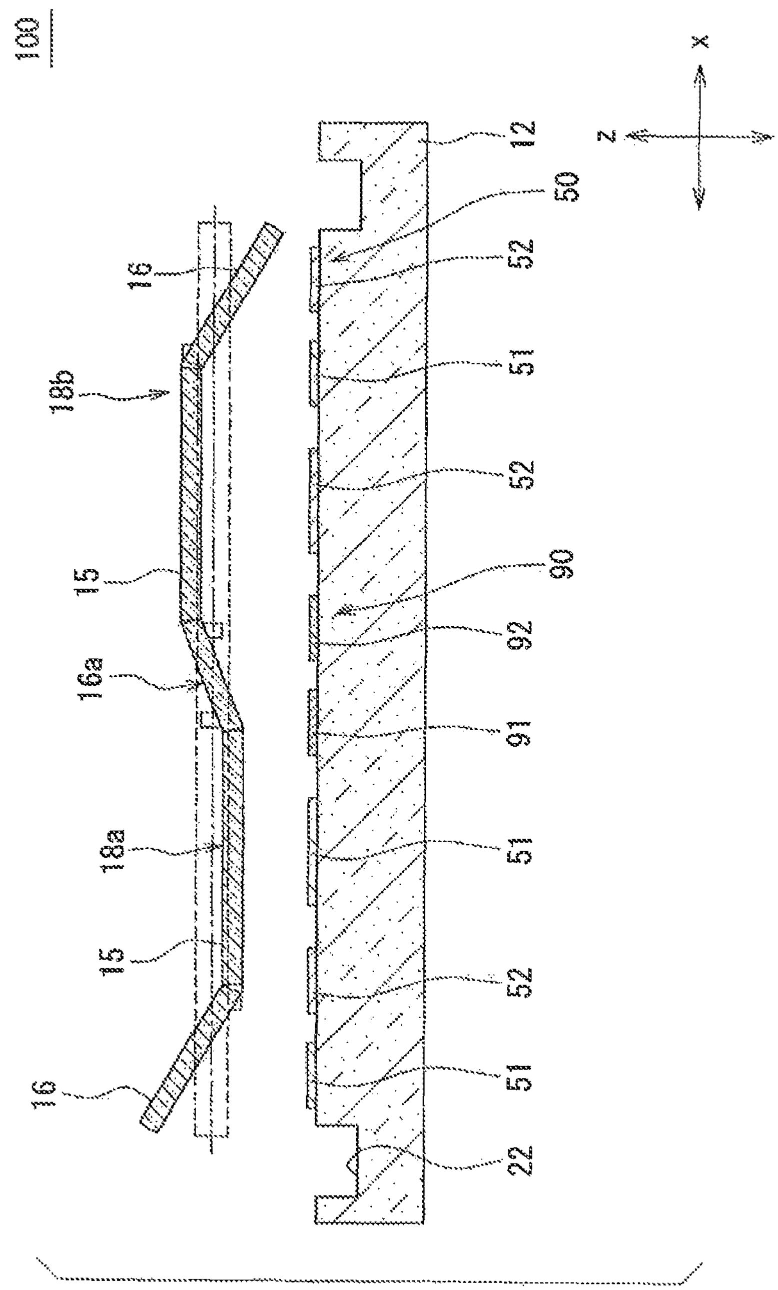
FIG. 9



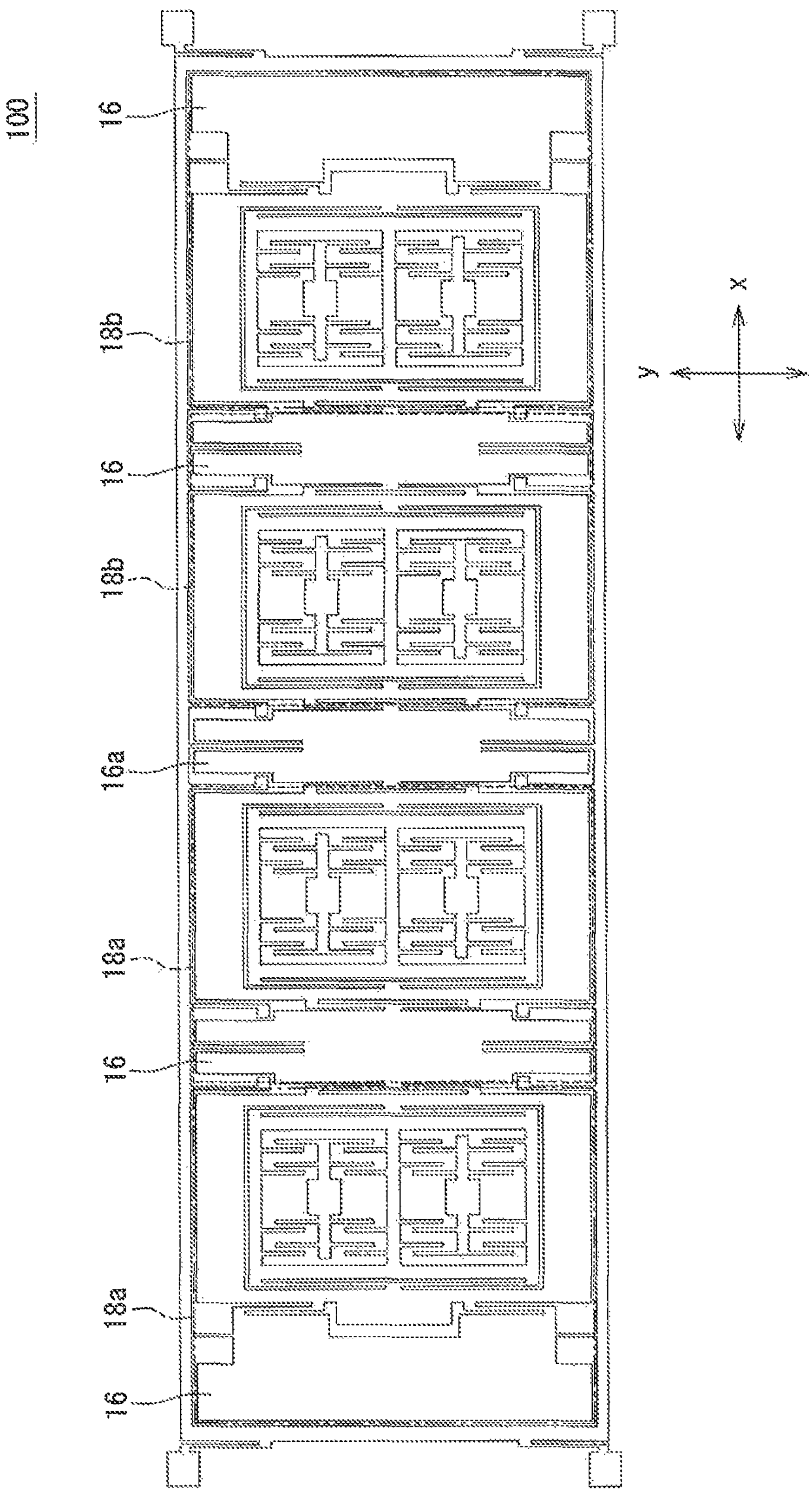
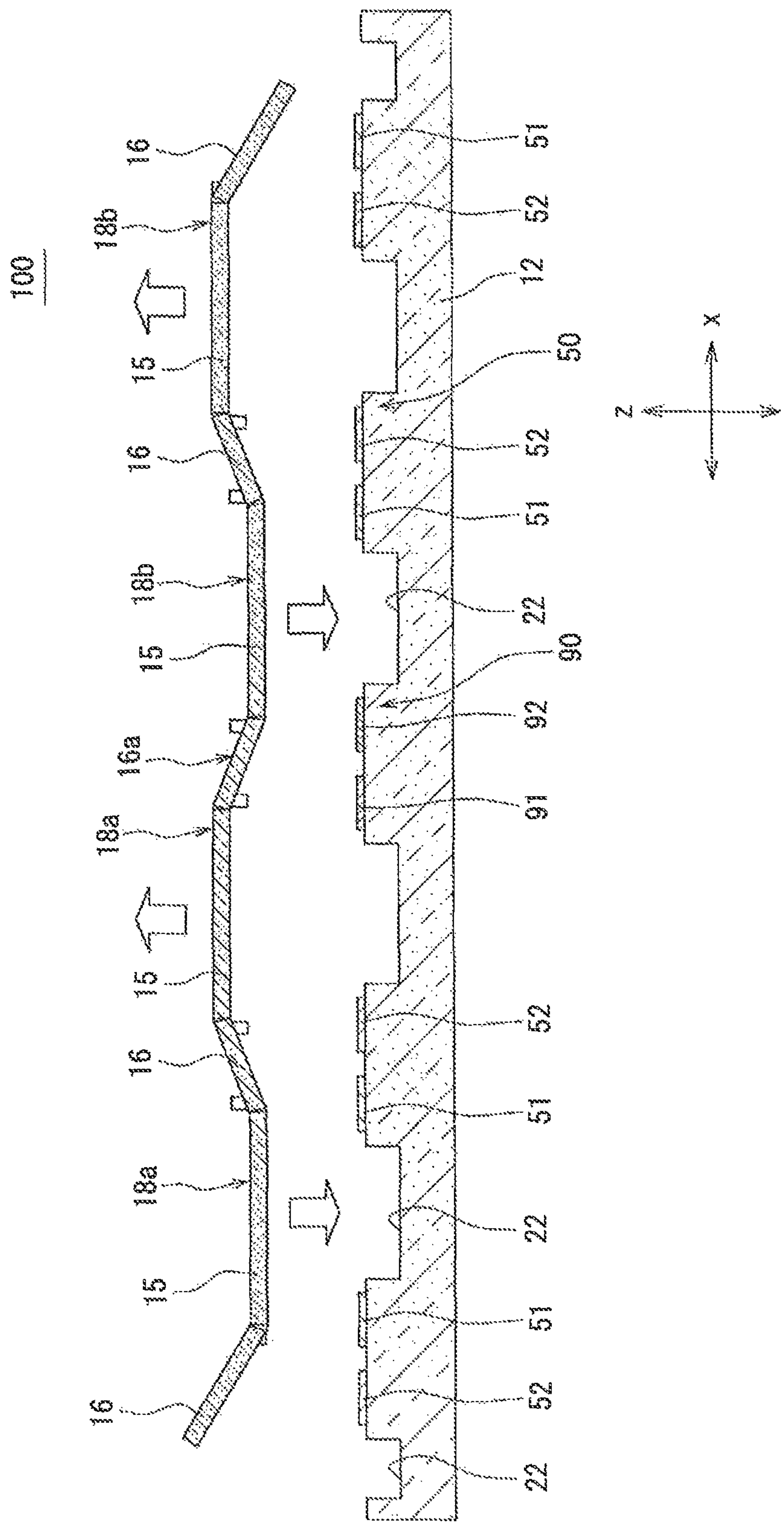


FIG. 10

FIG. 11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ANGULAR VELOCITY SENSOR

CROSS-REFERENCE TO RELATED APPLICATION

The present application is based on Japanese Patent Application No. 2012-56262 filed on Mar. 13, 2012, the disclosure of which is incorporated herein by reference.

TECHNICAL FIELD

The present disclosure relates to an angular velocity sensor that includes a vibrator, an excitation portion to vibrate the vibrator along z direction, and a detection device to detect displacement along x direction of the vibrator.

BACKGROUND ART

[Patent Literature 1] US-2010/0064805 A

Patent Literature 1 proposes a sensing frame that includes a base, a first rail and a second rail that move along a first direction, and a first guiding arm and a second guiding arm that link the first rail to the second rail. The first guiding arm is attached to a first anchor of the base so as to rotate about a second direction orthogonal to the first direction; the second guiding arm is attached to a second anchor of the base so as to rotate about a third direction parallel with the second direction. Movement of the first rail and the second rail is attained along the first direction with the opposite phases. Angular velocity is detected by sensing the displacement of the rails due to the application of the angular velocity. The first direction may apply to the direction in which the base and the first rail are linked.

In the sensing frame indicated in Patent Literature 1, two rails are linked with the guiding arms and the guiding arms are attached to the anchors. This configuration causes the vibration, which is produced when the rails move, to propagate to the anchors via the guiding arms. The vibration propagating to the anchors are reflected by the base, and the vibration reflected returns to the rails via the anchors and guiding arms. As a result, the movement state of the rails become unstable, involving a defect to decrease the detection accuracy in angular velocity.

SUMMARY

It is an object to provide an angular velocity sensor that suppresses a decline of a detection accuracy in angular velocity.

To achieve the object, according to an example of the present disclosure, an angular velocity sensor is provided to include a vibrator; a substrate; an anchor device; a linkage beam device; an excitation portion; and a detection portion. The vibrator is located in x-y plane specified by x direction and y direction that are orthogonal to each other. The substrate is separated away from the vibrator along z direction perpendicular to the x-y plane. The anchor device is extended from the substrate to the x-y plane in which the vibrator is located. The linkage beam device links the anchor device to the vibrator, the linkage beam being able to twist about the y direction. The excitation portion vibrates the vibrator along the z direction. The detection portion detects an angular velocity based on a displacement along the x direction of the vibrator. Further, the angular velocity sensor is characterized in that the vibrator includes a linkage region that links with the linkage beam device, and the linkage region becomes a wave node when the vibrator vibrates along the z direction.

According to the example of the present disclosure, in the vibrator, the linkage region linked with the linkage beam device serves as a wave node when the vibrator vibrates along the z direction. The wave node is a point, in which the vibration is zero and the amplitude or displacement is zero. Therefore, under the above configuration, the vibration of the vibrator is suppressed from propagating to the substrate via the linkage beam device and the anchor device. This configuration inhibits the substrate from reflecting the vibration propagating to the substrate and also inhibits the reflected vibration from returning to the vibrator. As a result, the vibrational state of the vibrator is inhibited from becoming unstable; the detection accuracy in the angular velocity is inhibited from decreasing.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features, and advantages of the present disclosure will become more apparent from the following detailed description made with reference to the accompanying drawings. In the drawings:

FIG. **1** is a top view illustrating an outline configuration of an angular velocity sensor according to a first embodiment;

FIG. **2** is a sectional view illustrating a driving state of a vibrator in FIG. **1**;

FIG. **3** is a block diagram illustrating an electrical route of the angular velocity sensor;

FIG. **4** is a top view illustrating an outline configuration of a vibrator;

FIG. **5** is a perspective view illustrating a driving state of a vibrator;

FIG. **6** is a top view illustrating a displacement of a vibrator when an angular velocity is applied along y direction;

FIG. **7** is a top view illustrating a displacement of a vibrator when an external force is applied along x direction;

FIG. **8** is a top view illustrating a modification example of a vibrator;

FIG. **9** is a sectional view illustrating a driving state of a vibrator in FIG. **8**;

FIG. **10** is a top view illustrating a modification example of a vibrator; and

FIG. **11** is a sectional view illustrating a driving state of a vibrator in FIG. **10**.

DETAILED DESCRIPTION

The following describes embodiments of the present disclosure with reference to drawings.

First Embodiment

The following will explain an angular velocity sensor according to a first embodiment with reference to FIGS. **1** to **7**. FIG. **1** provides hatching to facing ranges R**1** to R**4** (mentioned later) of a vibrator **11**; the facing ranges R**1** to R**4** face electrodes **51**, **52**, **91**, **92**. FIG. **2** illustrates a sectional view of the vibrator **11** along a penetrating direction L**1** illustrated in FIG. **1**, while illustrating an immovable state of the vibrator **11** using a range surrounded by broken lines. FIG. **4** to FIG. **7** omit components unnecessary for explaining a moving state of the vibrator **11** to illustrate schematically. Schematic illustration contains the components overlapping, which should not be overlapping actually. FIG. **4** to FIG. **7** are obtained from a simulation, and a little different from the configuration in FIG. **1** to FIG. **3**; however, they have the same configuration in a fundamental portion (featured portion of the present disclosure).

The following defines three axes of x axis, y axis, and z axis; three axes are orthogonal to each other. Further, a direction parallel with the x axis is referred to as an x direction; a direction parallel with the y axis is referred to as a y direction; and a direction parallel with the z axis is referred to as a z direction. Yet further, x-y plane is defined as being specified by the x direction and the y direction; y-z plane is defined as being specified by the y direction and the z direction; and z-x plane is defined as being specified by the z direction and the x direction.

With reference to FIG. **1** to FIG. **3**, an angular velocity sensor **100** mainly includes a sensor portion **10**, an excitation portion **50**, and a detection portion **70**. The sensor portion **10** includes a vibrator **11** that is vibrated by the excitation portion **50**. When an angular velocity is applied to the vibrator **11** in a vibrational state, Coriolis force arises in the direction, which is orthogonal to (i) the vibrating direction and (ii) the applying direction of the angular velocity, to displace the vibrator **11** in the applying direction of the Coriolis force. This displacement of the vibrator **11** is detected by the detection portion **70**, permitting the detection or calculation of an angular velocity. The angular velocity sensor **100** according to the present embodiment is used under a vacuum atmosphere.

The sensor portion **10** includes the following: a vibrator **11**; a substrate **12** located separate from the vibrator **11** along the z direction; an anchor device **13** which includes four main anchors extended to a height position of the vibrator **11**; and a linkage beam device **14** which links the anchor device **13** with the vibrator **11**. The vibrator **11** is linked with the anchor device **13** via the linkage beam device **14**; the vibrator **11** appears to be floating over the substrate **12**. The vibrator **11** is vibrated by the excitation portion **50** as described above; the vibrator **11** has a linkage region P1 that is linked with the linkage beam device **14** and the linkage region P1 becomes a wave node when the vibrator **11** vibrates along the z direction.

The vibrator **11** includes up-down weights **15**; inclination weights **16** linked with the linkage beam device **14**; and twist beams **17** which link the inclination weights **16** with the up-down weights **15**. The vibrator **11** includes one inclination weight **16** located at a center (in the x direction) of the vibrator **11**, which will be referred to as a central weight **16***a*. A left side is defined herein as being the left side in the drawings viewed from the central weight **16***a* along the x direction; a right side is defined herein as being the right side in the drawings viewed from the central weight **16***a* along the x direction. The number of up-down weights **15** and the number of inclination weights **16** are individually identical in both the left side and the right side. A unit weight portion **18** is defined as collectively including one up-down weight **15**, one inclination weight **16** next to the one up-down weight **15**, and twist beams **17** linking between the one up-down weight **15** and the one inclination weight **16**. The unit weight portion(s) **18** located in the left side are referred to as a left unit weight **18***a*; the unit weight portion(s) **18** located in the right side are referred to as a right unit weight **18***b*. It is noted that the drawing omits the reference sign **18** but illustrates the reference signs **18***a* and **18***b*.

In the present embodiment, the vibrator **11** has (i) the left unit weigh **18***a* that has only one unit weight portion **18** and (ii) the right unit weight **18***b* that has only one right unit weight portion **18**. In this vibrator **11**, the left and right unit weights **18***a* and **18***b* are formed to be symmetrical with respect to a first penetrating direction L**1** (indicated with one-dot chain line in FIG. **1**) that penetrates through a center of each of the unit weights **18***a* and **18***b* themselves along the x direction; the left and right unit weights **18***a* and **18***b* are formed to be symmetrical with respect to a second penetrating direction L**2** (indicated with two-dot chain line in FIG. **1**) that penetrates through a center of the central weight **16***a* along the y direction.

The up-down weight **15** includes a first frame portion **19** having an outer face linked with the twist beam **17**; a second frame portion **20** located in a range surrounded by an inner face of the first frame portion **19**; and detection beams **21** that link the first frame portion **19** with the second frame portion **20**, the detection beams **21** having flexibility along the x direction.

The first frame portion **19** includes two first bars **19***a* and **19***b* extended along the x direction, and two second bars **19***c* and **19***d* extended along the y direction. The bars **19***a* to **19***d* are linked at respective end portions, forming a loop having an external outline of a quadrangular shape along the x-y plane. The thickness along the y direction of each of the first bars **19***a* and **19***b* is larger than the thickness along the x direction of each of the second bars **19***c* and **19***d*. A center of the second bar **19***d* projects towards the inclination weight **16**; the center is thicker than others. The second bar **19***c* includes two projections on a face facing the central weight **16***a* in order to link with both end portions of one twist beam **17**. The second bar **19***d* includes two projections on a face facing the inclination weight **16** in order to link with one end portion of each of two twist beams **17**. The second bar **19***c* includes one projection on a face facing the second frame portion **20** in order to link with a center of one detection beam **21**. The second bar **19***d* includes one projection on a face facing the second frame portion **20** in order to link with a center of one detection beam **21**. Further, in the second bar **19***d*, the projection from the face facing the inclination weight **16** is formed away along the y direction from the projection towards the second frame portion **20**.

The second frame portion **20** includes two third bars **20***a* and **20***b* extended along the x direction, two fourth bars **20***c* and **20***d* extended along the y direction, and one fifth bar **20***e* extended along the x direction. The bars **20***a* to **20***d* are linked at respective end portions, forming a loop having an external outline of a quadrangular shape along the x-y plane. An inside of the loop is equally divided into two by the fifth bar **20***e*, providing a planar shape similar to Japanese Kanji character "日" (similar to the shape of two adjoining quadrangles arranged along the y direction on the x-y plane). The thickness along the y direction of each of the third bars **20***a* and **20***b* and the fifth bar **20***e* is smaller than the thickness along the x direction of each of the fourth bars **20***c* and **20***d*; the end portions of the fifth bar **20***e* are linked with centers of inner faces of the fourth bars **20***c* and **20***d*, respectively. The fourth bar **20***c* includes a projection that is provided at each of both end portions of a face facing the second bar **19***c* in order to link with each of both end portions of one detection beam **21**. The fourth bar **20***d* includes a projection that is provided at each of both end portions of a face facing the second bar **19***d* in order to link with each of both end portions of one detection beam **21**.

In the present embodiment, the inclination weight **16** included in the unit weight portion **18** is different from the inclination weight **16** (central weight **16***a*) located at the center of the vibrator **11** in respect of shape, and, therefore, will be explained to be differentiated from the central weight **16***a*.

The inclination weight **16** includes a base portion **16***b* having a convex along the x-y plane to be partially convex towards the central weight **16***a*, and a projection portion **16***c* further projecting from each of both end portions of the convex of the base portion **16**b. Each of the two projections **16**c includes one projection on a face facing the inclination weight **16** in order to link with the other end portion of the twist beam **17**; a side face along the y direction of the projection portion **16**c is linked with one end portion of the second linkage beam **27**, mentioned later. This configuration permits an end portion along the x direction separating away from the central weight **16**a of the base portion **16**b to serve as a free end.

The central weight **16**a includes two wing portions **16**d each having a convex along the x-y plane to be partially convex towards the up-down weight **15**, and a linkage portion **16**e linking the two wing portions **16**d to each other. Each of the two wing portions **16**d includes one projection on a face facing the up-down weight **16** in order to link with a center of the twist beam **17**; a side face along the y direction of the linkage portion **16**e is linked with one end portion of the second linkage beam **27**, mentioned later.

The twist beam **17** has a shape extended along the y direction, which serves as an axial; the twist beam **17** can twist around the axis. In the present embodiment, the central weight **16**a and the up-down weight **15** are linked via one twist beam **17**; the inclination weight **16** and the up-down weight **15** are linked via two twist beams **17**. A center of the twist beam **17** linking between the central weight **16**a and the up-down weight **15** is linked with a projection formed in the central weight **16**a; both end portions of the twist beam **17** are linked with projections formed in the up-down weight **15**. One end portion of the twist beam **17** linking between the inclination weight **16** and the up-down weight **15** is linked with a projection formed in the up-down weight **15**; the other end portion of the twist beam **17** is linked with a projection formed in the inclination weight **16**.

The substrate **12** supports the vibrator **11** via (i) the anchor device **13** and (ii) the linkage beam device **14**. With reference to FIG. **2**, the substrate **12** includes concave portions **22** on a facing range facing the vibrator **11**; the concave portions **22** are provided such that a thickness along the z direction is concave locally in a direction separating from the vibrator **11**. In the present embodiment, the concave portions **22** are formed in a facing range facing the up-down weight **15** in the substrate **12**, and in a facing range facing the free end of the inclination weight **16** in the substrate **12**.

The anchor device **13**, which includes the four main anchors, fixes the vibrator **11** to the substrate **12** using the linkage beam device **14**. As indicated in FIG. **1**, the four main anchors of the anchor device **13** are formed outside of the range surrounded by a main frame portion **25** mentioned later. The main anchor of the anchor device **13** is located in each of four corners of the main frame portion **25**, and has a projection which is linked with the other end portion of the first linkage beam **26**, which will be mentioned later.

In addition, first anchors **23**, which have functions different from the anchor device **13**, are located in a range surrounded by the main frame portion **25**; second anchors **24**, which have functions different from the anchor device **13**, are located in a range surrounded by the second frame portion **20**. The first anchors **23** achieve the function supporting the main frame portion **25**, and the second anchors **24** achieve the function supporting second detection electrodes **72** mentioned later. Two first anchors **23** are provided in each of two ranges between the central weight **16**a and the up-down weights **15**. One second anchor **24** is provided in each of four ranges formed by the division by the second frame portion **20**.

The linkage beam device **14** links the anchor device **13** with the vibrator **11**. The linkage beam device **14** includes the main frame portion **25** surrounding the vibrator **11**, first linkage beams **26** which link the anchor device **13** with the main frame portion **25**, and second linkage beams **27** which link the vibrator **11** with the frame portion. The linkage beam device **14** according to the present embodiment further includes third linkage beams **28** which link the main frame portion **25** with the first anchors **23**.

The main frame portion **25** includes two sixth bars **25**a and **25**b extended along the x direction, and two seventh bars **25**c and **25**d extended along the y direction. The bars **25**a to **25**d are linked at respective end portions, forming a loop having an external outline of a quadrangular shape along the x-y plane. The thickness along they direction of each of the sixth bars **25**a and **25**b is identical to the thickness along the x direction of each of the seventh bars **25**c and **25**d. In addition, an inner face of each of the sixth bars **25**a and **25**b is linked with the other end portions of two second linkage beams **27** and the other end portions of two third linkage beams **28**; an outer face of each of the seventh bars **25**c and **25**d is provided with two projections that are linked with the other end portions of two first linkage beams **26**.

The linkage beams **26** to **28** are shaped of being extended along the y direction. The first linkage beam **26** has flexibility along the x direction. Each of the second linkage beam **27** and the third linkage beam **28** has an axis that is an extended direction of each of the second linkage beam **27** and the third linkage beam **28**; each of the second linkage beam **27** and the third linkage beam **28** can twist around the axis. One end portion of the first linkage beam **26** is linked with a projection formed in an outer face of each of the seventh bars **25**c and **25**d; the other end portion is linked with a projection formed in the anchor device **13**. One end portion of the second linkage beam **27** is linked with a side face of the projection portion **16**c of the inclination weight **16**; the other end portion is linked with an outer face of each of the sixth bars **25**a and **25**b. One end portion of the second linkage beam **27** is linked with a side face of the linkage portion **16**e of the central weight **16**a; the other end portion is linked with an inner face of each of the sixth bars **25**a and **25**b. One end portion of the third linkage beam **28** is linked with the first anchor **23**; the other end portion is linked with an inner face of each of the sixth bars **25**a and **25**b.

It is noted that in the inclination weight **16** (central weight **16**a), the linkage region P1 linked with the second linkage beam **27** is the same as the region functioning as a wave node in the inclination weight **16** (central weight **16**a) when the vibrator **11** vibrates. In addition, the beams **17**, **27**, and **28** have flexibility along the x direction, but have more difficulty in bending along the x direction than the first linkage beam **26**. In other words, the first linkage beam **26** bends easier along the x direction than the beams **17**, **27**, and **28**.

The excitation portion **50** vibrates the vibrator **11** along the z direction. More specifically, the excitation portion **50** vibrates the left unit weight **18**a and the right unit weight **18**b, which are arranged along the x direction and symmetrical with respect to the central weight **16**a, with opposite phases, thereby vibrating the vibrator **11** along the z direction. With reference to FIGS. **2** and **3**, the excitation portion **50** includes first driving electrodes **51** and second driving electrodes **52**, which are formed in the substrate **12**; and a voltage application portion **53** which applies driving voltages to the driving electrodes **51** and **52** and the vibrator **11**. The first driving electrodes **51** and the second driving electrodes **52** face the vibrator **11** along the z direction (i.e., the vibrator **11** is viewed in the z direction from the first driving electrodes **51** and the second driving electrodes **52**). The voltage application portion **53** has a function to apply, as driving voltages, alternating-current voltages of the opposite phases to the first driving electrodes **51** and the second driving electrodes **52**, and a constant voltage to the vibrator **11**. The application of the driving voltages produces an attractive force (repulsive force) between the vibrator **11** and the first driving electrodes **51**, and repulsive force (attractive force) between the vibrator **11** and the second driving electrodes **52**. Thereby, the vibrator **11** vibrates along the z direction.

In the present embodiment, as indicated in FIG. **2**, one first driving electrode **51** and one second driving electrode **52**, which are arranged along the x direction, face the inclination weight **16** along the z direction. Further, the first driving electrode **51** facing the inclination weight **16** of the left unit weight **18***a* and the second driving electrode **52** facing the inclination weight **16** of the right unit weight **18***b* are arranged along the x direction and symmetrical with respect to the central weight **16***a*. In contrast, the second driving electrode **52** facing the inclination weight **16** of the left unit weight **18***a* and the first driving electrode **51** facing the inclination weight **16** of the right unit weight **18***b* are arranged along the x direction and symmetrical with respect to the central weight **16***a*. As indicated with hatching in FIG. **1**, the shape of a facing range R**1** of the inclination weight **16** facing the first driving electrode **51** along the z direction and the shape of the facing range R**2** of the inclination weight **16** facing the second driving electrode **52** along the z direction are individually symmetrical with respect to a penetrating direction L**1**. In addition, a third penetrating direction (unshown) penetrates through the linkage region P**1**, which is linked with the second linkage beam **27** in the inclination weight **16**, along the y direction; the division by the third penetrating direction forms two ranges. The first facing range R**1** is located in one range of those two ranges, and the second facing range R**2** is located in the remaining range of those two ranges. Thereby, when the one range formed from the division by the third penetrating direction receives a repulsive force (attractive force), the remaining range receives an attractive force (repulsive force). The magnitude of the repulsive force (attractive force) received by the one range is the same as the magnitude of the attractive force (repulsive force) received by the remaining range.

The detection portion **70** detects an angular velocity based on a displacement along the x direction of the vibrator **11**. More specifically, the detection portion **70** detects an angular velocity based on a displacement along the x direction of each of the left and right unit weights **18***a* and **18***b*. The detection portion **70** includes first detection electrodes **71** formed in an inner face of the second frame portion **20**; supporting beams **74** extended along the x direction from the second anchors **24**; second detection electrodes **72** formed in the supporting beams **74** and facing the first detection electrodes **71** along the x direction; and an angular velocity detection portion **73** to detect an angular velocity based on a change (displacement along the x direction of the vibrator **11**) in an electrostatic capacity of a capacitor composed of the detection electrodes **71**, **72**.

As illustrated in FIG. **1**, the first detection electrodes **71** have shapes to be extended along the y direction from (i) the inner faces of the third bars **20***a* and **20***b*, and (ii) the side face of the fifth bar **20***e*; the second detection electrodes **72** have shapes to be extended along the y direction from the side faces of the supporting beams **74**. The first detection electrodes **71** and the second detection electrodes **72** bite each other and face mutually along the x direction, thereby forming a bipectinate shaped electrode. The first detection electrodes **71** are displaced against the second detection electrodes **72** according to a displacement of the second frame portion **20**; this varies the electrostatic capacity of the capacitor.

The angular velocity detection portion **73** detects an angular velocity based on a difference between an electrostatic capacity of a right capacitor and an electrostatic capacity of a left capacitor; the left capacitor is composed of the first detection electrodes **71** formed in the up-down weight **15** of the left unit weight **18***a* whereas the right capacitor is composed of the first detection electrodes **71** formed in the up-down weight **15** of the right unit weight **18***b*.

The angular velocity sensor **100** according to the present embodiment has a monitor portion **90** which observes a vibrational state of the vibrator **11**. The monitor portion **90** includes a first monitor electrode **91** and a second monitor electrode **92** which are formed in the substrate **12** to face the vibrator **11** along the z direction; and a determination portion **93** which determines a vibrational state of the vibrator **11** based on a potential fluctuation of each of the first monitor electrode **91** and the second monitor electrode **92** due to the variation of the vibrator **11**. In the present embodiment, the first monitor electrode **91** faces the wing portion **16***d*, which is next to the left unit weight **18***a*, along the z direction; the second monitor electrode **92** faces the wing portion **16***d*, which is next to the right unit weight **18***b*, along the z direction. Further, in the present embodiment, as illustrated by hatching in FIG. **1**, the shape of a facing range R**3** of the wing portion **16***d* facing the first monitor electrode **91** along the z direction and the shape of a facing range R**4** of the wing portion **16***d* facing the second monitor electrode **92** along the z direction are individually symmetrical with respect to the first penetrating direction L**1**. The area of the third facing range R**3** and the area of the fourth facing range R**4** are equal.

The following will explain an operation of the angular velocity sensor **100** and a detection of an angular velocity according to the present embodiment with reference to FIG. **2** and FIG. **4** to FIG. **7**. As indicated in FIG. **4**, before the driving voltages are applied to the vibrator **11**, the vibrator **11** is in a state to be flat along the x-y plane.

As explained above, the first driving electrode **51** facing the inclination weight **16** of the left unit weight **18***a* and the second driving electrode **52** facing the inclination weight **16** of the right unit weight **18***b* are arranged along the x direction and symmetrical with respect to the central weight **16***a*. In contrast, the second driving electrode **52** facing the inclination weight **16** of the left unit weight **18***a* and the first driving electrode **51** facing the inclination weight **16** of the right unit weight **18***b* are arranged along the x direction and symmetrical with respect to the central weight **16***a*. Therefore, when the current-alternating voltages of the opposite phases are applied to the first driving electrodes **51** and the second driving electrodes **52** and a fixed voltage is applied to the vibrator **11**, electrostatic forces are applied to symmetrical positions of the left unit weight **18***a* and the right unit weight **18***b* in the opposite directions along the z direction. Then, the beams **17**, **27**, and **28** take their extended directions (y direction) as directions of axes, and twist about the axes; the inclination weight **16** and the central weight **16***a* move in the shape of the seesaw along the y-z plane centering on the linkage region P**1** linked with the second linkage beam **27**. As a result, the left unit weight **18***a* and the right unit weight **18***b* carry out the coupled oscillation in the opposite directions along the z direction. As illustrated in FIG. **2** and FIG. **5**, when the up-down weight **15** of the left unit weight **18***a* is displaced in the direction approaching the substrate **12**, the up-down weight **15** of the right unit weight **18***b* is displaced in the direction separating away from the substrate **12**. Although not illustrated, conversely, when the up-down weight **15** of the left unit weight **18***a* is displaced in the direction separating away from the substrate **12**, the up-down weight **15** of the right unit weight **18***b* is displaced in the direction approaching the substrate **12**. In this case, the up-down weight **15** does not rotate along the z-x plane, and vibrates along the z direction while maintaining constant the facing area with the substrate **12** along the z direction.

When an angular velocity is applied along the y direction in the above-mentioned vibrational state, a Coriolis force along the x direction arises in the vibrator **11**, displacing the vibrator **11** (second frame portion **20**) along the x direction. Thereby, the relative distance between the detection electrodes **71** and **72** varies, and the electrostatic capacity between the detection electrodes **71** and **72** also varies. As described above, the left unit weight **18***a* and the right unit weight **18***b* are displaced to the mutually opposite directions along the z direction. Therefore, the left unit weight **18***a* and the right unit weight **18***b* receive the Coriolis force in the mutually opposite applying directions. As illustrated in FIG. **6**, the detection beams **21** bend along the x direction; the second frame portions **20** of the unit weights **18***a* and **18***b* are displaced in the mutually opposite directions along the x direction. As a result, the first detection electrodes **71** included in the left capacitor and the first detection electrodes **71** included in the right capacitor are also displaced in the opposite directions along the x direction. The electrostatic capacities of the left capacitor and the right capacitor also change conversely. Therefore, the Coriolis force (angular velocity) is detected by obtaining a difference between the respective capacity variations of the left capacitor and right capacitor.

It is noted that when an external force such as acceleration along the x direction is applied to the vibrator **11**, the second frame portion **20** of the up-down weight **15** moves also according to the external force. Thereby, the relative distance between the detection electrodes **71** and **72** varies, and the electrostatic capacity between the detection electrodes **71** and **72** also varies. However, as indicated in FIG. **7**, the external force displaces the second frame portions **20** of the unit weights **18***a* and **18***b* in the same direction. Therefore, the first detection electrodes **71** included in the left capacitor and the first detection electrodes **71** included in the right capacitor are displaced in the same direction while variations of the relative distances between the detection electrodes **71** and **72** are identical in both the left unit weight **18***a* and the right unit weight **18***b*. Therefore, as described above, the capacity changes due to the external force are canceled by obtaining a difference of the capacity changes of the left capacitor and the right capacitor.

The following will explain an effect of the angular velocity sensor **100** according to the present embodiment. As explained above, in the vibrator **11**, the linkage region P**1** linked with the linkage beam device **14** becomes a wave node when the vibrator **11** vibrates along the z direction. The wave node is a point, in which the vibration is zero and the amplitude is zero. Therefore, according to the above configuration, the vibration of the vibrator **11** is suppressed from propagating to the substrate **12** via the linkage beam device **14** and the anchor device **13**. Therefore, the vibration propagating to the substrate **12** is inhibited from being reflected by the substrate **12** and then returning to the vibrator **11**. As a result, the vibrational state of the vibrator **11** is inhibited from becoming unstable, and the detection accuracy in the angular velocity is inhibited from decreasing.

The vibrator **11** includes the left unit weight **18***a* and the right unit weight **18***b*, which are symmetrical with respect to the central weight **16***a*. The excitation portion **50** vibrates the left unit weight **18***a* and the right unit weight **18***b*, which are arranged along the x direction and symmetrical with respect to the central weight **16***a*, with opposite phases; thereby the detection portion **70** detects an angular velocity based on a displacement along the x direction of each of the unit weights **18***a* and **18***b*.

Under this configuration, when an angular velocity is applied along the y direction, the left unit weight **18***a* and the right unit weight **18***b* move in the opposite directions along the x direction. By contrast, when an external force is applied along the x direction, the left unit weight **18***a* and the right unit weight **18***b* move in the direction in which the external force is applied. Therefore, if a difference between a displacement of the left unit weight **18***a* and a displacement of the right unit weight **18***b* is detected, an angular velocity is detectable while canceling an influence of the external force. This suppresses the decline of the detection accuracy in the angular velocity due to the external force.

In the vibrator **11**, the shape of the first facing range R**1**, and the shape of the second facing range R**2** are symmetrical with respect to the first penetrating direction L**1**.

This configuration is different from the configuration where the shape of the first facing range and the shape of the second facing range are unsymmetrical with respect to the first penetrating direction, thereby inhibiting the vibrator **11** from moving along the y-z plane. As a result, the vibrational state of the vibrator **11** is inhibited from becoming unstable, and the detection accuracy in the angular velocity is inhibited from decreasing.

The linkage beam device **14** includes the main frame portion **25** surrounding the vibrator **11**, the first linkage beams **26** which links the anchor device **13** with the frame portion, and the second linkage beams **27** which links the vibrator **11** with the main frame portion **25**. The first linkage beams **26** have flexibility along the x direction.

Under this configuration, the first linkage beams **26** bend when an external force is applied along the x direction, the stress applied to the vibrator **11** due to bending is reduced. As a result, a displacement of the vibrator **11** due to the external force is suppressed and the decline in the detection accuracy of the angular velocity is suppressed.

Under the present embodiment, the first linkage beams **26** bend easier along the x direction than the beams **17**, **27**, and **28**. Thus, as compared with the configuration where the first linkage beams are not bent easier along the x direction than other beams, when an external force is applied along the x direction, a stress applied to the vibrator **11** due to bending of the first linkage beams **26** is reduced effectively.

The up-down weight **15** includes the first frame portion **19** having an outer face linked with the twist beams **17**; the second frame portion **20** located in a range surrounded by an inner face of the first frame portion **19**; and the detection beams **21** that link the first frame portion **19** with the second frame portion **20** and have flexibility along the x direction. Further, the detection portion **70** includes the first detection electrodes **71** formed in the inner face of the second frame portion **20**, the supporting beams **74** extended along the x direction from the second anchors **24**, the second detection electrodes **72** formed in the supporting beams **74**, and the angular velocity detection portion **73** to detect an angular velocity based on a change (displacement in the x direction of the vibrator **11**) in an electrostatic capacity of a capacitor composed of the detection electrodes **71**, **72** which face each other along the x direction.

Under this configuration, the vibration in the z direction of the first frame portion **19** and the movement in the x direction of the second frame portion **20** are separated from each other with the detection beams **21** serving as a border, suppressing the variation in the movement of the second frame portion **20** due to the vibration of the first frame portion **19**. This configuration suppresses the variations in the facing area and facing gap between the first detection electrode **71** and the second detection electrode **72** due to the vibration of the first frame portion **19**, and also suppresses the variation in the change of the electrostatic capacity of the capacitor formed between the first detection electrode **71** and the second detection electrode **72**, i.e., the displacement along the x direction of the vibrator **11**. As a result, the decline of the detection accuracy in the angular velocity due to the vibration of the first frame portion **19** is suppressed.

The substrate **12** includes concave portions **22** on a facing range facing the vibrator **11**; the concave portions **22** are provided such that a thickness along the z direction is concave locally in a direction separating from the vibrator **11**.

This configuration inhibits the vibrator **11** from colliding with the substrate **12** when the vibrator **11** vibrates along the z direction. In addition, differently from the present embodiment using the angular velocity sensor **100** under the vacuum atmosphere, when the angular velocity sensor **100** is used under air atmosphere, the damping is inhibited from arising between the vibrator **11** and the substrate **12**. Thus, the vibrational state of the vibrator **11** is inhibited from becoming unstable, and the detection accuracy in the angular velocity is inhibited from decreasing.

The monitor portion **90** is provided to observe a vibrational state of the vibrator **11**. This permits the observation of the vibrational state of the vibrator **11**.

The linkage beam device **14** according to the present embodiment further includes the third linkage beams **28** which link the main frame portion **25** with the first anchors **23**.

This supports the main frame portion **25** with the third linkage beams **28**; therefore, the main frame portion **25** is inhibited from vibrating due to an application of an external force. Thus, the vibrational state of the vibrator **11** is inhibited from becoming unstable, and the detection accuracy in the angular velocity is inhibited from decreasing.

In the vibrator **11** according to the present embodiment, the left unit weight **18***a* has a single unit weight portion **18**; the right unit weight **18***b* has a single unit weight portion **18**. This configuration inhibits the increase of the physique of the angular velocity sensor **100**, as compared with the configuration including more than one left unit weight portion and more than one right unit weight portion. In addition, since the length of the main frame portion **25** becomes shorter, the resonance frequency of the main frame portion **25** becomes shorter. This inhibits the main frame portion **25** from vibrating due to an application of an external force, and inhibits the vibrational state of the vibrator **11** from becoming unstable. As a result, the decline of the detection accuracy in the angular velocity is inhibited.

The preferred embodiment of the present disclosure is thus described; however, without being restricted to the embodiment mentioned above, the present disclosure can be variously modified as long as not deviating from the scope thereof.

Modification

In the present embodiment, as an example, one first driving electrode **51** and one second driving electrode **52**, which are arranged along the x direction, face the inclination weight **16** along the z direction. Without need to be limited thereto, as illustrated in FIG. **8** and FIG. **9**, the up-down weight **15** of the left unit weight **18***a* may face the first driving electrode **51** along the z direction; the up-down weight **15** of the right unit weight **18***b* may face the second driving electrode **52** along the z direction. This configuration permits the left unit weight **18***a* and the right unit weight **18***b* to vibrate with the opposite phases, vibrating the vibrator **11** along the z direction.

In the above modification example, as indicated in FIG. **8**, the shape of a facing range R**5** of the up-down weight **15** facing the first driving electrode **51** along the z direction and the shape of a facing range R**6** of the up-down weight **15** facing the second driving electrode **52** along the z direction are individually symmetrical with respect to the first penetrating direction. Differently from the configuration where the shape of the fifth facing range R**5** and the shape of the sixth facing range R**6** are unsymmetrical with respect to the first penetrating direction, the vibrator **11** is inhibited from moving along the y-z plane. As a result, the vibrational state of the vibrator **11** is inhibited from becoming unstable, and the decline of the detection accuracy in the angular velocity is inhibited. Although unshown, the up-down weight **15** of the left unit weight **18***a* may face the second driving electrode **52** along the z direction; the up-down weight **15** of the right unit weight **18***b* may face the first driving electrode **51** along the z direction.

In the present embodiment, as an example, in the vibrator **11**, the left unit weight **18***a* has one unit weight portion **18** and the right unit weight **18***b* has one unit weight portion **18**. However, the number of the unit weight portions **18** included in the vibrator **11** is not limited to the above example. As illustrated in FIG. **10** and FIG. **11**, in the vibrator **11**, the left unit weight **18***a* may include two unit weight portions **18** and the right unit weight **18***b* may include two unit weight portions **18**. In this manner, as the number of the unit weight portions **18** in each of the left unit weight **18***a* and the right unit weight **18***b* increases, the number of the capacitors increases, improving the detection accuracy of the angular velocity. In the case of the modification example, numbers are assigned in order leftwardly from the central weight **16***a* such as the first left unit weight portion **18***a* and the second left unit weight portion **18***a*; numbers are assigned in order rightwardly from the central weight **16***a* such as the first right unit weight portion **18***b* and the second right unit weight portion **18***b*. The inclination weight **16** of the first left unit weight portion **18***a* and the inclination weight **16** of the first right unit weight portion **18***b* have the same shape as the shape of the central weight **16***a*. Further, the inclination weight **16** of the second left unit weight portion **18***a* and the inclination weight **16** of the second right unit weight portion **18***b* have the same shape as the shape of the inclination weight **16** described in the first embodiment. In this manner, the respective inclination weights **16** of the unit weights **18***a* and **18***b* which are furthest from the central weight **16***a* have the same shape as the shape of the inclination weight **16** described in the first embodiment; other inclination weights **16** of the unit weights **18***a* and **18***b* have the same shape as the shape of the central weight **16***a*. In order to make clear the border lines of the unit weight portions included in the left and right unit weights **18***a* and **18***b* in FIG. **10**, the first left unit weight portion **18***a* and the first right unit weight portion **18***b* are indicated by being surrounded with the broken lines; the second left unit weight portion **18***a* and the second right unit weight portion **18***b* are indicated by being surrounded with the one-dot chain lines.

In the present embodiment, as examples, the vibrator **11** is symmetrical with respect to the first penetrating direction L**1** and symmetrical with respect to the second penetrating direction L**2**. There is no need to be limited thereto. As long as the vibrator **11** vibrates along the z direction while including the linkage region P**1** liked with the linkage beam **11** becomes a wave node when the vibrator **11** vibrates along the z direction, any shape of the vibrator **11** may be adopted.

The present embodiment indicated the example in which the concave portion **22** is formed in the substrate **12**. However, there may be provided with no concave portion **22**.

In the present embodiment, as an example, the first facing range R**1** is located in one range formed by the division by the third penetrating direction; the second facing range R**2** is located in the remaining range. There is no need to be limited thereto. If the inclination weight **16** moves in the shape of the seesaw along the z direction by using the linkage region P**1** as the wave node, the facing ranges R**1** and R**2** may not be limited to the above example. As total, a configuration may be adopted as needed where a repulsive force (attractive force) is applied to one range of the inclination weight **16** while an attractive force (repulsive force) is applied to the remaining range.

The present embodiment indicates an example that the monitor electrodes **91** and **92** face the central weight **16***a*. However, the monitor electrodes **91** and **92** may face an inclination weight **16** included in the unit weight portion **18**. In this case, the first monitor electrode **91** may be located in one range formed by the division by the third penetrating direction; the second monitor electrode **92** may be located in the remaining range.

Further, the present embodiment indicates an example that the shape of the third facing range R**3** and the shape of the fourth facing range R**4** are symmetrical with respect to the first penetrating direction L**1**. However, the shape of the third facing range R**3** and the shape of the fourth facing range R**4** may not be symmetrical with respect to the first penetrating direction L**1**. Thus, the area of the third facing range R**3** and the area of the fourth facing range R**4** may not be equal.

The present embodiment did not explain an amplitude of the vibrator **11**. The amplitude of vibration along the z direction of the vibrator **11** may be about one tenth the thickness along the z direction of the vibrator **11**, for instance.

Aspects of the disclosure described herein are set out in the following clauses.

According to a first aspect of the present disclosure, an angular velocity sensor is characterized by including: a vibrator **11** that is located in x-y plane specified by x direction and y direction that are orthogonal to each other; a substrate **12** that is separated away from the vibrator **11** along z direction perpendicular to the x-y plane; an anchor device **13** that is extended from the substrate **12** to the x-y plane in which the vibrator **11** is located; a linkage beam device **14** that links the anchor device **13** to the vibrator **11**, the linkage beam being able to twist about the y direction; an excitation portion **50** that vibrates the vibrator **11** along the z direction; and a detection portion **70** that detects an angular velocity based on a displacement along the x direction of the vibrator **11**. Further, the angular velocity sensor is characterized in that the vibrator **11** includes a linkage region P1 that links with the linkage beam device **14**, and the linkage region P1 becomes a wave node when the vibrator **11** vibrates along the z direction.

According to a second aspect being optional, the vibrator **11** may include up-down weights **15**, inclination weights **16** linked to the linkage beam device **14**, and twist beams **17** that link the inclination weights **16** to the up-down weights **15**, the twist linkage beam being able to twist about the y direction. A left side and a right side may be respectively referred to as one and an other of two sides along the x direction viewed from a central weight **16***a*, which is one of the inclination weights **16** and located at a center in the x direction of the vibrator **11**. A unit weight portion **18** may be defined as including one up-down weight **15**, one inclination weight **16** next to the one up-down weight **15**, and twist beams **17** linking the one up-down weight **15** with the one inclination weight **16**. The vibrator **11** may include (i) a left unit weight **18***a*, which includes at least one unit weight portion **18**, on the left side and (ii) a right unit weight **18***b*, which includes at least one unit weight portion **18**, on the right side. The number of the at least one unit weight portion **18** of the left unit weight **18***a* and the number of the at least one unit weight portion **18** of the right unit weight **18***b* may be identical to each other such that the left unit weight **18***a* and the right unit weight **18***b* are arranged along the x direction and symmetrical with respect to the central weight **16***a* of the vibrator **11**. The excitation portion **50** may vibrate the left unit weight **18***a* and the right unit weight **18***b* with opposite phases, respectively. The detection portion **70** may detect an angular velocity based on a displacement along the x direction of each of the left unit weight **18***a* and the right unit weight **18***b*.

Under this configuration, when an angular velocity is applied along the y direction, the left unit weight **18***a* located on the left side and the right unit weight **18***b* located on the right side move to opposite directions along the x direction. By contrast, when an external force is applied along the x direction, the left unit weight **18***a* and the right unit weight **18***b* move to an applying direction of the external force. Therefore, if a difference between a displacement of the left unit weight **18***a* and a displacement of the right unit weight **18***b* is detected, an angular velocity is detectable while canceling an influence of the external force. Thereby, the decline of the detection accuracy in the angular velocity due to the external force is suppressed.

According to a third aspect being optional, the excitation portion **50** may include (i) first driving electrodes **51** and second driving electrodes **52**, which are formed in the substrate **12**, and (ii) a voltage application portion **53** that applies driving voltages to the first driving electrodes **51**, the second driving electrodes **52**, and the vibrator **11**. The first driving electrodes **51** and the second driving electrodes **52** may face the vibrator **11** along the z direction. The voltage application portion **53** may apply, as driving voltages, alternating-current voltages of the opposite phases to the first driving electrodes **51** and the second driving electrodes **52**, and a constant voltage to the vibrator **11**.

When attractive force repulsive force arises between the vibrator **11** and the first driving electrodes **51**, repulsive force attractive force arises between the vibrator **11** and the second driving electrodes **52**. Thereby, the vibrator **11** vibrates along the z direction.

According to a fourth aspect being optional, one first driving electrode **51** and one second driving electrode **52** may be arranged along the x direction and face the inclination weight **16** along the z direction. According to this, the inclination weight **16** vibrates along the z direction at a center that is positioned at the linkage region P1 linked with the linkage beam device **14**; the vibrator **11** vibrates along the z direction.

According to a fifth aspect being optional, the first driving electrode **51** facing the inclination weight **16** of the left unit weight **18***a* and the second driving electrode **52** facing the inclination weight **16** of the right unit weight **18***b* may be arranged along the x direction and symmetrical with respect to the central weight **16***a* of the vibrator **11**; and the second driving electrode **52** facing the inclination weight **16** of the left unit weight **18***a* and the first driving electrode **51** facing the inclination weight **16** of the right unit weight **18***b* may be arranged along the x direction and symmetrical with respect to the central weight **16***a* of the vibrator **11**.

Under this configuration, the left unit weight **18***a* and the right unit weight **18***b*, which are arranged along the x direction and symmetrical with respect to the central weight **16***a* located at the center of the vibrator **11**, vibrate with opposite phases. Thereby, the vibrator **11** vibrates along the z direction.

According to a sixth aspect being optional, in the vibrator **11**, each of a shape of a facing range R**1** of the inclination weight **16** facing the first driving electrode **51** along the z direction and a shape of a faced range R**2** of the inclination weight **16** facing the second driving electrode **52** along the z direction are individually symmetrical with respect to a penetrating direction L**1** penetrating, along the x direction, through a center of each of the unit weight portions **18**.

This configuration is different from the configuration where a shape of a facing range R**1** of the inclination weight facing the first driving electrode along the z direction and a shape of a facing range R**2** of the inclination weight facing the second driving electrode along the z direction are individually unsymmetrical with respect to a penetrating direction L**1** penetrating, along the x direction, through a center of each of the unit weight portions **18**. Thus, the vibrator **11** is inhibited from moving in y-z plane specified by the y direction and the z direction. As a result, the vibrational state of the vibrator **11** is inhibited from becoming unstable, and the detection accuracy in the angular velocity is inhibited from decreasing.

According to a seventh aspect being optional, the up-down weight **15** of the left unit weight **18***a* may face a first driving electrode **51** along the z direction; the up-down weight **15** of the right unit weight **18***b* may face a second driving electrode **52** along the z direction.

Under this configuration, the left unit weight **18***a* and the right unit weight **18***b*, which are arranged along the x direction and symmetrical with respect to the central weight **16***a* located at the center of the vibrator **11**, vibrate with opposite phases. Thereby, the vibrator **11** vibrates along the z direction.

According to an eighth aspect being optional, a shape of a facing range R**5** of the up-down weight **15** facing the first driving electrode **51** along the z direction and a shape of a facing range R**6** of the up-down weight **15** facing the second driving electrode **52** along the z direction may be individually symmetrical with respect to a penetrating direction L**1** penetrating, along the x direction, through a center of each of the unit weight portions **18**.

This configuration is different from the configuration where a shape of a facing range R**5** of the up-down weight facing the first driving electrode along the z direction of z and a shape of the facing range R**6** of the up-down weight facing the second driving electrode along the z direction are individually unsymmetrical with respect to a penetrating direction L**1** penetrating along the x direction through a center of each of the unit weight portions. Thus, the vibrator **11** is inhibited from moving in the y-z plane. As a result, the vibrational state of the vibrator **11** is inhibited from becoming unstable, and the detection accuracy in the angular velocity is inhibited from decreasing.

According to a ninth aspect being optional, the linkage beam device **14** may include a main frame portion **25** surrounding the vibrator **11**, first linkage beams **26** which link the anchor device **13** with the main frame portion **25**, and second linkage beams **27** which link the vibrator **11** with the frame portions. The first linkage beams **26** may have flexibility along the x direction; the second linkage beams **27** may have property to twist about the y direction.

Under this configuration, the first linkage beams **26** bend when an external force is applied along the x direction. Bending of the first linkage beams **26** reduces stress applied to the vibrator **11**. As a result, a displacement of the vibrator **11** due to the external force is suppressed, and the decline in the detection accuracy of the angular velocity is suppressed.

According to a tenth aspect being optional, the up-down weight **15** may include (i) a first frame portion **19** having an outer face linked with the twist beam **17**, (ii) a second frame portion **20** located in a range surrounded by an inner face of the first frame portion **19**, and (iii) detection beams **21** that link the first frame portion **19** with the second frame portion **20**, the detection beams **21** having flexibility along the x direction. The detection portion **70** may include (i) a first detection electrode **71** formed in an inner face of the second frame portion **20**, (ii) a second detection electrode **72** linked with the anchor device **13** and facing the first detection electrode **71** in either the x direction or they direction, and (iii) an angular velocity detection portion **73** that detects an angular velocity based on a change of electrostatic capacity of a capacitor formed between the first detection electrode **71** and the second detection electrode **72**.

Under this configuration, the vibration along the z direction of the first frame portion **19** and the movement along the x direction of the second frame portion **20** are separated from each other with the detection beams **21** serving as a border, suppressing the variation in the movement of the second frame portion **20** due to the vibration of the first frame portion **19**. A facing area and a facing gap are formed between the first detection electrode **71** and the second detection electrode **72**. The facing area and the facing gap undergo variations due to the vibration of the first frame portion **19**. The above configuration suppresses such variations in the facing area and the facing gap, and further suppresses the variation in the change of the electrostatic capacity of the capacitor formed between the first detection electrode **71** and the second detection electrode **72**, i.e., the displacement along the x direction of the vibrator **11**. As a result, the decline of the detection accuracy in the angular velocity due to the vibration of the first frame portion **19** is suppressed.

According to an eleventh aspect being optional, the substrate **12** may include a region **22**, which is in a facing range facing the vibrator **11**. The region **22** may have a z-directional thickness that is locally recessed towards a direction separating from the vibrator **11**. This configuration inhibits the vibrator **11** from colliding with the substrate **12** when the vibrator **11** vibrates along the z direction. In addition, when the angular velocity sensor **100** is used under air atmosphere, the damping is inhibited from arising between the vibrator **11** and the substrate **12**. Thus, the vibrational state of the vibrator **11** is inhibited from becoming unstable, and the detection accuracy in the angular velocity is inhibited from decreasing.

According to a twelfth aspect being optional, a monitor portion **90** may be further provided to observe a vibrational state of the vibrator **11**. This permits the observation of the vibrational state of the vibrator **11**.

While the present disclosure has been described with reference to preferred embodiments thereof, it is to be understood that the disclosure is not limited to the preferred embodiments and constructions. The present disclosure is intended to cover various modification and equivalent arrangements. In addition, while the various combinations and configurations, which are preferred, other combinations and configurations, including more, less or only a single element, are also within the spirit and scope of the present disclosure.

What is claimed is:

1. An angular velocity sensor comprising:

a vibrator located in an x-y plane specified by an x direction and a y direction that are orthogonal to each other;

a substrate that is separated away from the vibrator in a z direction perpendicular to the x-y plane;

an anchor device extended from the substrate to the x-y plane in which the vibrator is located;

a linkage beam device that links the anchor device with the vibrator, the linkage beam device being able to twist about the y direction;

an excitation portion that vibrates the vibrator along the z direction; and

a detection portion that detects an angular velocity based on a displacement along the x direction of the vibrator, wherein

the vibrator includes a linkage region that is linked with the linkage beam device, the linkage region becoming a wave node when the vibrator vibrates along the z direction,

the vibrator includes up-down weights, inclination weights linked to the linkage beam device, and twist beams that link the inclination weights to the up-down weights, the twist beams being able to twist about the y direction,

a left side and a right side are respectively referred to as one and an other of two sides along the x direction viewed from a central weight, which is one of the inclination weights and located at a center in the x direction of the vibrator;

a unit weight portion is defined as including one up-down weight, one inclination weight next to the one up-down weight, and twist beams linking the one up-down weight with the one inclination weight;

the vibrator includes

a left unit weight, which includes at least one unit weight portion, on the left side and

a right unit weight, which includes at least one unit weight portion, on the right side;

a number of the at least one unit weight portion of the left unit weight and a number of the at least one unit weight portion of the right unit weight are identical to each other such that the left unit weight and the right unit weight are arranged along the x direction and symmetrical with respect to the central weight of the vibrator;

the excitation portion vibrates the left unit weight and the right unit weight with opposite phases, respectively; and

the detection portion detects an angular velocity based on a displacement along the x direction of each of the left unit weight and the right unit weight;

the up-down weight includes a first frame portion having an outer face linked with the twist beams, a second frame portion located in a range surrounded by an inner face of the first frame portion, and detection beams that link the first frame portion with the second frame portion, the detection beams having flexibility along the x direction; and

the detection portion includes

first detection electrodes formed in an inner face of the second frame portion,

second detection electrodes, which are linked with the anchor device, the second detection electrodes facing the first detection electrodes in either the x direction or the y direction, and

an angular velocity detection portion that detects an angular velocity based on changes of electrostatic capacities of capacitors formed between the first detection electrodes and the second detection electrodes.

2. The angular velocity sensor according to claim **1**, wherein:

the excitation portion includes

first driving electrodes and second driving electrodes, which are formed in the substrate, and

a voltage application portion that applies driving voltages to the first driving electrodes, the second driving electrodes, and the vibrator;

the first driving electrodes and the second driving electrodes face the vibrator along the z direction; and

the voltage application portion applies, as driving voltages, alternating-current voltages of the opposite phases to the first driving electrodes and the second driving electrodes, and

a constant voltage to the vibrator.

3. The angular velocity sensor according to claim **2**, wherein:

one of the first driving electrodes and one of the second driving electrodes, which are arranged along the x direction, face one of the inclination weights along the z direction.

4. The angular velocity sensor according to claim **3**, wherein:

the first driving electrode facing the inclination weight of the left unit weight and the second driving electrode facing the inclination weight of the right unit weight are arranged along the x direction and symmetrical with respect to the central weight of the vibrator; and

the second driving electrode facing the inclination weight of the left unit weight and the first driving electrode facing the inclination weight of the right unit weight are arranged along the x direction and symmetrical with respect to the central weight of the vibrator.

5. The angular velocity sensor according to claim **4**, wherein:

in the vibrator, a shape of a facing range of the inclination weight facing the first driving electrode along the z direction and a shape of a facing range of the inclination weight facing the second driving electrode along the z direction are individually symmetrical with respect to a penetrating direction penetrating, along the x direction, through a center of each of the unit weight portions.

6. The angular velocity sensor according to claim **2**, wherein:

the up-down weight of one of the left unit weight and the right unit weight faces the first driving electrode along the z direction; and

the up-down weight of an other of the left unit weight and the right unit weight faces the second driving electrode along the z direction.

7. The angular velocity sensor according to claim **6**, wherein:

a shape of a facing range of the up-down weight facing the first driving electrode along the z direction and a shape of a facing range of the up-down weight facing the second driving electrode along the z direction are individually symmetrical with respect to a penetrating direction penetrating, along the x direction, through a center of each of the unit weight portions.

8. The angular velocity sensor according to claim **1**, wherein:

the linkage beam device includes a main frame portion surrounding the vibrator, first linkage beams which link the anchor device with the main frame portion, and second linkage beams which link the vibrator with the main frame portion;

the first linkage beams have flexibility along the x direction; and

the second linkage beams have property to twist about the y direction.

9. The angular velocity sensor according to claim **1**, wherein:

the substrate includes a region that is in a facing range facing the vibrator, the region having a thickness along the z direction to be locally recessed towards a direction separating from the vibrator.

10. The angular velocity sensor according to claim **1**, further comprising:

a monitor portion that observes a vibrational state of the vibrator.

11. An angular velocity sensor comprising:

a vibrator located in an x-y plane specified by an x direction and a y direction that are orthogonal to each other;

a substrate that is separated away from the vibrator in a z direction perpendicular to the x-y plane;

an anchor device extended from the substrate to the x-y plane in which the vibrator is located;

a linkage beam device that links the anchor device with the vibrator, the linkage beam device being able to twist about the y direction;

an excitation portion that vibrates the vibrator along the z direction; and

a detection portion that detects an angular velocity based on a displacement along the x direction of the vibrator, wherein

the vibrator includes up-down weights, inclination weights linked to the linkage beam device, and twist beams that link the inclination weights to the up-down weights, the twist beams being able to twist about the y direction,

a left side and a right side are respectively referred to as one and an other of two sides along the x direction viewed from a central weight, which is one of the inclination weights and located at a center in the x direction of the vibrator,

a unit weight portion is defined as including one up-down weight, one inclination weight next to the one up-down weight, and twist beams linking the one up-down weight with the one inclination weight,

the vibrator includes

a left unit weight, which includes at least one unit weight portion, on the left side, and

a right unit weight, which includes at least one unit weight portion, on the right side,

a number of the at least one unit weight portion of the left unit weight and a number of the at least one unit weight portion of the right unit weight are identical to each other such that the left unit weight and the right unit weight are arranged along the x direction and symmetrical with respect to the central weight of the vibrator,

the linkage beam device includes

a main frame portion surrounding the vibrator,

first linkage beams which link the anchor device with the main frame portion, and

second linkage beams which link the vibrator with the main frame portion,

the vibrator includes linkage regions that link the second linkage beams with the inclination weight of each of the left unit weight and the right unit weight that are farthest from the central weight located at the center of the vibrator, the linkage region becoming a wave node when the vibrator vibrates along the z direction, and

the inclination weight of each of the left unit weight and the right unit weight that are farthest from the central weight is divided into a projection portion and a base portion by a penetrating direction that is deviated from a center in the x direction of the inclination weight towards the central weight,

the penetrating direction penetrating along the y direction through the linkage region in the inclination weight,

the base portion being farther from the central weight than the projection portion and broader than the projection portion, permitting an end portion of the base portion along the x direction separating away from the central weight to serve as a free end.

12. The angular velocity sensor according to claim **11**, wherein

the excitation portion vibrates the left unit weight and the right unit weight with opposite phases, respectively,

the detection portion detects an angular velocity based on a displacement along the x direction of each of the left unit weight and the right unit weight,

the first linkage beams have flexibility along the x direction, and

the second linkage beams being configured to twist about the y direction.

13. The angular velocity sensor according to claim **12**, wherein

the excitation portion includes

first driving electrodes and second driving electrodes, which are formed in the substrate, and

a voltage application portion that applies driving voltages to the first driving electrodes, the second driving electrodes, and the vibrator,

the first driving electrodes and the second driving electrodes face the vibrator along the z direction, and

the voltage application portion applies, as driving voltages, alternating-current voltages of the opposite phases to the first driving electrodes and the second driving electrodes, and

a constant voltage to the vibrator.

14. The angular velocity sensor according to claim **13**, wherein

one of the first driving electrodes and one of the second driving electrodes, which are arranged along the x direction, face one of the inclination weights along the z direction.

15. The angular velocity sensor according to claim **14**, wherein

the first driving electrode facing the inclination weight of the left unit weight and the second driving electrode facing the inclination weight of the right unit weight are arranged along the x direction and symmetrical with respect to the central weight of the vibrator, and

the second driving electrode facing the inclination weight of the left unit weight and the first driving electrode facing the inclination weight of the right unit weight are arranged along the x direction and symmetrical with respect to the central weight of the vibrator.

16. The angular velocity sensor according to claim **15**, wherein

in the vibrator, a shape of a facing range of the inclination weight facing the first driving electrode along the z direction and a shape of a facing range of the inclination weight facing the second driving electrode along the z direction are individually symmetrical with respect to a penetrating direction penetrating, along the x direction, through a center of each of the unit weight portions.

17. The angular velocity sensor according to claim **13**, wherein

the up-down weight of one of the left unit weight and the right unit weight faces the first driving electrode along the z direction, and

the up-down weight of an other of the left unit weight and the right unit weight faces the second driving electrode along the z direction.

18. The angular velocity sensor according to claim **17**, wherein

a shape of a facing range of the up-down weight facing the first driving electrode along the z direction and a shape of a facing range of the up-down weight facing the second driving electrode along the z direction are individually symmetrical with respect to a penetrating direction penetrating, along the x direction, through a center of each of the unit weight portions.

19. The angular velocity sensor according to claim **11**, wherein

the up-down weight includes a first frame portion having an outer face linked with the twist beams, a second frame portion located in a range surrounded by an inner face of the first frame portion, and detection beams that link the first frame portion with the second frame portion, the detection beams having flexibility along the x direction, and

the detection portion includes

first detection electrodes formed in an inner face of the second frame portion,

second detection electrodes, which are linked with the anchor device, the second detection electrodes facing the first detection electrodes in either the x direction or the y direction, and

an angular velocity detection portion that detects an angular velocity based on changes of electrostatic capacities of capacitors formed between the first detection electrodes and the second detection electrodes.

20. The angular velocity sensor according to claim **11**, wherein

the substrate includes a region that is in a facing range facing the vibrator, the region having a thickness along the z direction to be locally recessed towards a direction separating from the vibrator.

21. The angular velocity sensor according to claim **11**, further comprising

a monitor portion that observes a vibrational state of the vibrator.

22. An angular velocity sensor comprising:

a vibrator located in an x-y plane specified by an x direction and a y direction that are orthogonal to each other;

a substrate that is separated away from the vibrator in a z direction perpendicular to the x-y plane;

an anchor device extended from the substrate to the x-y plane in which the vibrator is located;

a linkage beam device that links the anchor device with the vibrator, the linkage beam device being able to twist about the y direction;

an excitation portion that vibrates the vibrator along the z direction; and

a detection portion that detects an angular velocity based on a displacement along the x direction of the vibrator, wherein

the vibrator includes a linkage region that is linked with the linkage beam device, the linkage region becoming a wave node when the vibrator vibrates along the z direction,

the vibrator includes up-down weights, inclination weights linked to the linkage beam device, and twist beams that link the inclination weights to the up-down weights, the twist beams being able to twist about the y direction,

a left side and a right side are respectively referred to as one and an other of two sides along the x direction viewed from a central weight, which is one of the inclination weights and located at a center in the x direction of the vibrator,

a unit weight portion is defined as including one up-down weight, one inclination weight next to the one up-down weight, and twist beams linking the one up-down weight with the one inclination weight,

the vibrator includes

a left unit weight, which includes at least one unit weight portion, on the left side and

a right unit weight, which includes at least one unit weight portion, on the right side,

a number of the at least one unit weight portion of the left unit weight and a number of the at least one unit weight portion of the right unit weight are identical to each other such that the left unit weight and the right unit weight are arranged along the x direction and symmetrical with respect to the central weight of the vibrator,

the excitation portion vibrates the left unit weight and the right unit weight with opposite phases, respectively,

the detection portion detects an angular velocity based on a displacement along the x direction of each of the left unit weight and the right unit weight,

the linkage beam device includes a main frame portion surrounding the vibrator, first linkage beams which link the anchor device to the main frame portion, and second linkage beams which link the vibrator to the main frame portion,

the second linkage beams, which link the vibrator to the main frame portion, extend along the y direction while being configured to twist about the y direction, and

the first linkage beams, which link the anchor device to the main frame portion, extend along the y direction while having flexibility along the x direction.

23. The angular velocity sensor according to claim **22**, wherein

the excitation portion includes

first driving electrodes and second driving electrodes, which are formed in the substrate, and

a voltage application portion that applies driving voltages to the first driving electrodes, the second driving electrodes, and the vibrator,

the first driving electrodes and the second driving electrodes face the vibrator along the z direction, and

the voltage application portion applies, as driving voltages, alternating-current voltages of the opposite phases to the first driving electrodes and the second driving electrodes, and

a constant voltage to the vibrator.

24. The angular velocity sensor according to claim **23**, wherein

one of the first driving electrodes and one of the second driving electrodes, which are arranged along the x direction, face one of the inclination weights along the z direction.

25. The angular velocity sensor according to claim **24**, wherein

the first driving electrode facing the inclination weight of the left unit weight and the second driving electrode facing the inclination weight of the right unit weight are arranged along the x direction and symmetrical with respect to the central weight of the vibrator, and

the second driving electrode facing the inclination weight of the left unit weight and the first driving electrode facing the inclination weight of the right unit weight are arranged along the x direction and symmetrical with respect to the central weight of the vibrator.

26. The angular velocity sensor according to claim 25, wherein

in the vibrator, a shape of a facing range of the inclination weight facing the first driving electrode along the z direction and a shape of a facing range of the inclination weight facing the second driving electrode along the z direction are individually symmetrical with respect to a penetrating direction penetrating, along the x direction, through a center of each of the unit weight portions.

27. The angular velocity sensor according to claim 23, wherein

the up-down weight of one of the left unit weight and the right unit weight faces the first driving electrode along the z direction, and

the up-down weight of an other of the left unit weight and the right unit weight faces the second driving electrode along the z direction.

28. The angular velocity sensor according to claim 27, wherein

a shape of a facing range of the up-down weight facing the first driving electrode along the z direction and a shape of a facing range of the up-down weight facing the second driving electrode along the z direction are individually symmetrical with respect to a penetrating direction penetrating, along the x direction, through a center of each of the unit weight portions.

29. The angular velocity sensor according to claim 22, wherein

the up-down weight includes a first frame portion having an outer face linked with the twist beams, a second frame portion located in a range surrounded by an inner face of the first frame portion, and detection beams that link the first frame portion with the second frame portion, the detection beams having flexibility along the x direction, and

the detection portion includes

first detection electrodes formed in an inner face of the second frame portion,

second detection electrodes, which are linked with the anchor device, the second detection electrodes facing the first detection electrodes in either the x direction or the y direction, and

an angular velocity detection portion that detects an angular velocity based on changes of electrostatic capacities of capacitors formed between the first detection electrodes and the second detection electrodes.

30. The angular velocity sensor according to claim 22, wherein

the substrate includes a region that is in a facing range facing the vibrator, the region having a thickness along the z direction to be locally recessed towards a direction separating from the vibrator.

31. The angular velocity sensor according to claim 22, further comprising

a monitor portion that observes a vibrational state of the vibrator.

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